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BIONIC HAND

Restoring Sense of Touch Via Prosthetics

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MESSAGE FROM THE DIRECTOR

In an ever changing, technologically advancing world, we as a country and defense community are consistently aiming to remain ahead of our adversaries. HDIAC's eight focus areas cover the depth and breadth of some of the most challenging areas across the globe. As a Department of Defense Information Analysis Center, we are equally as excited to be an active part of the innovation solution. HDIAC leverages every tool at its disposal, including our Subject Matter Expert Network; information resources; the latest in science and technology; and research and development advancements from academia, industry and other government agencies to further the goals of the DoD. The HDIAC Journal provides us the opportunity to highlight these various components of our Center as well as R&D, S&T and other innovative developments across our focus areas.

Articles in this issue of the HDIAC Journal cover CBRN defense, medical, cultural studies and homeland defense and security.

HDIAC's Focus Areas:

- **Alternative Energy**
- **Biometrics**
- **CBRN Defense**
- **Cultural Studies**
- **Critical Infrastructure Protection**
- **Homeland Defense & Security**
- **Medical**
- **Weapons of Mass Destruction**

Two researchers from the University of Rhode Island are developing a new paper-based platform to conduct complex diagnoses, including traumatic brain injury, infections and exposure to toxic agents. Their research and diagnostic platform will be of specific interest and application to military members. In the absence of immediate health care, this provides our service members the ability to rapidly conduct meaningful diagnostic tests. This capability will extend beyond the battlefield and provide the same capacity to our first responders reacting to natural disasters, attacks or other unexpected events. Additionally, medical and military professionals working in remote locations will be able to provide doctors with much needed information to begin preparation for patient treatment.

Understanding and preparing for disasters with strategic forethought is a key element to mitigating long-term risks and the devolution of key societal structures. The cultural studies article looks at the growing threat of handling disaster management in megacities, specifically identifying the challenges in Lagos, Nigeria which can be applied to many of the other global megacities. Classifying the major social, governmental and security components of any megacity is a necessity. In Lagos, at least half of the city's 20 million inhabitants live in "alternately governed slums" or areas largely outside of government control. In the event of a natural disaster these areas become increasingly difficult to manage, access and provide much needed humanitarian aid. Gaining access to and understanding which local non-governmental organizations operate in various locations of any megacity would be a key element to providing any external disaster response. Providing our first responders and service members with this much needed information could significantly contribute to mission success.

After more than a decade of combat, many United States service members have suffered extensive battlefield trauma, specifically spinal injuries and the loss of limbs. In our featured article, five scientists from the University of Chicago highlight recent breakthroughs in prosthetics and neuroscience that aim to provide patients with the sense of touch through prosthetics. Some of the most recent advances intend to provide "meaningful and intuitive touch sensations" via biological sensors placed in the skin and through state-of-the-art prosthetics that mimic and move like human limbs. Through extensive research, they are attempting to produce

Stuart Stough, Director, HDIAC

sensations through the sensors in the prosthetic limb based on the amount of pressure applied through the fingers and/or thumb. These developments could significantly improve the mental, emotional and physical recovery for service members adjusting to life with new prosthetic limbs. Additionally, this could further improve the quality of life of all military and civilian amputees outfitted with this advanced prostheses.

In our last article, a researcher from Clemson University explores avenues to deal with the increasing amounts of global nuclear waste. Based on predictions, we are expected to see a 30 percent increase in global energy consumption and resulting waste products generated from fossil and spent nuclear fuels. The majority of these commercially spent nuclear fuels are stored on site with the aims of reprocessing 96 percent of the remaining uranium. Consequently, the remaining four percent of the waste stream represents a long-term concern as well as a proliferation threat. Security of nuclear waste and nonproliferation are key objectives for the DoD. This article explores techniques utilizing glasses and ceramics to reduce the proliferation threat and the ultimate immobilization of excess weapons-grade nuclear materials. These crystalline ceramics could ultimately provide a much needed solution and approach to dealing with excess nuclear waste generated from the civilian nuclear industry.

COMPLEX DIAGNOSIS

Using a New Paper-Based Platform

By: Constantine Anagnostopoulos, Ph.D. & Mohammad Faghri, Ph.D.

There is an overwhelming need to conduct diagnostic tests on soldiers deployed in remote locations, where a clinical laboratory is not available. To assess, for example, the extent of head trauma and brain injury; to identify whether an infection is due to dengue or malaria; to determine if illness is caused by a pathogen such as anthrax or other chemical or biological agents; to check for drug use; or to simply assess the soldiers' wellness. Early and timely detection of agents used to cause significant harm is critical to assisting the warfighter.

The ability to conduct meaningful tests at the doctor's office, at the pharmacy or home, at the scene of an emergency or in the ambulance on the way to the hospital has many benefits. One outcome could be lower health care costs because a doctor can make a diagnosis while the patient is still in his office. Testing at the pharmacy saves on doctor's visits. If a patient can be tested by emergency medical technicians, it will save time and possibly the person's life if the doctors in the emergency room know the test results. Doctors can be better prepared and may begin treatment, such as surgery, right away rather than wait to conduct relevant tests after the patient arrives at the hospital.

This need exists also for people who live in isolated communities around the world or even in space. With present day telecommunications, a test could be conducted locally and diagnosis made by a health professional located far away.

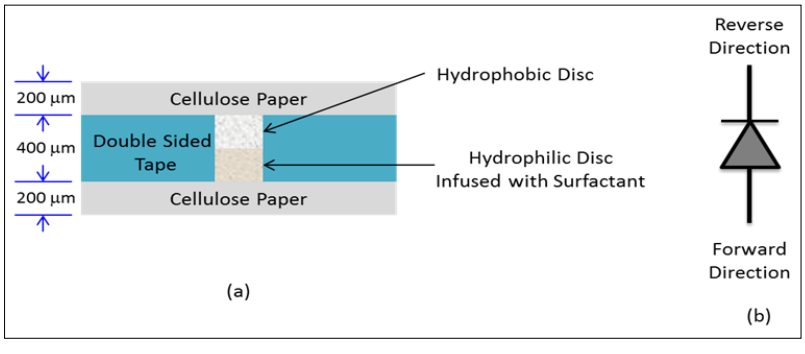
To meet this need, considerable effort has been expanded over the past 30 years on a class of devices called lateral flow assays. The term lateral flow serves to point out how the various fluids in these devices flow laterally, as opposed to the conventional diagnostic systems where the various reagents are added and removed vertically. There are two types of lateral flow assay devices: polymer-based and paper-based. Polymer-based devices have received excellent reviews. [1,2] Opko Health, Inc. [4] is commercializing a system based on this technology. A very comprehensive review of paper-based devices is offered in *Lab on a Chip Journal*. [3] Chembio, Inc. [4] is selling paper-based devices. In addition, there are a great number of companies selling home pregnancy test kits, which are the most successful of all lateral flow assays. [5]

Polymer-based lateral flow assays, despite their many apparent advantages, have not become commercially successful. There are a number of technical reasons for this. [6,7] The most important reason may be the power requirement and, the user must manipulate a number of buttons and other tasks for it to perform the test. In addition, they are not generally affordable by someone who wishes to conduct a test only once.

Paper-based devices, on the other hand, require no power because fluid flows naturally by capillarity. The user for a home pregnancy test kit, for example, simply loads the sample and reads the results about 20 minutes later. There are no buttons to push, no switches to flip on or off and, once finished, the test can be easily disposed (including by burning) to minimize contamination. The cost is low and affordable for a one time test. The major advantages of these paper-based devices, or test strips, as they are commonly known, are their low cost, ease of use, passive and autonomous operation and portability. The major shortcoming is that they can accept only one reagent, or sample fluid. Consequently, they are not able to conduct complex assays requiring multiple reagents and this limits their application space and sensitivity.

A new paper-based device maintains all the advantages of the current test strips but adds the ability to do more complex tests.

These new types of lateral flow



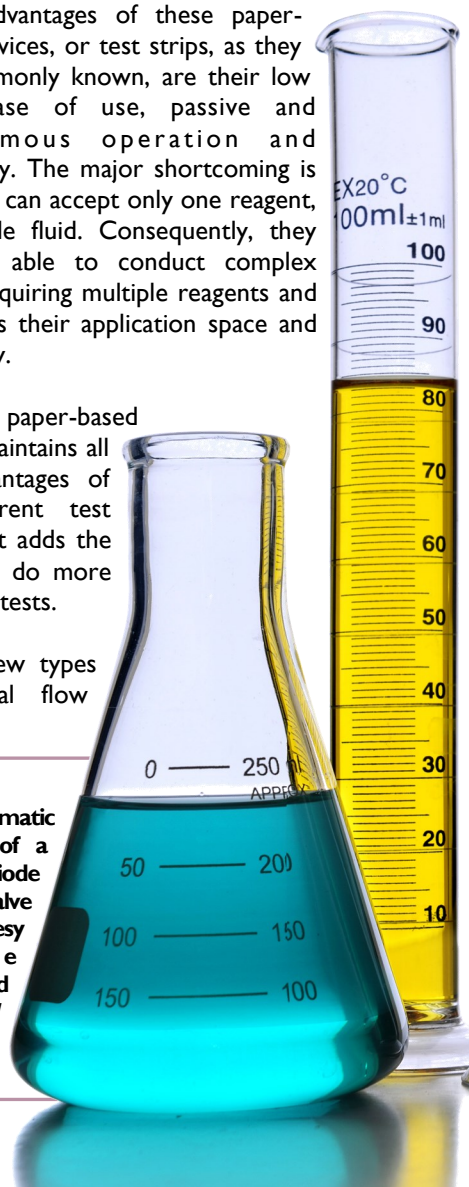
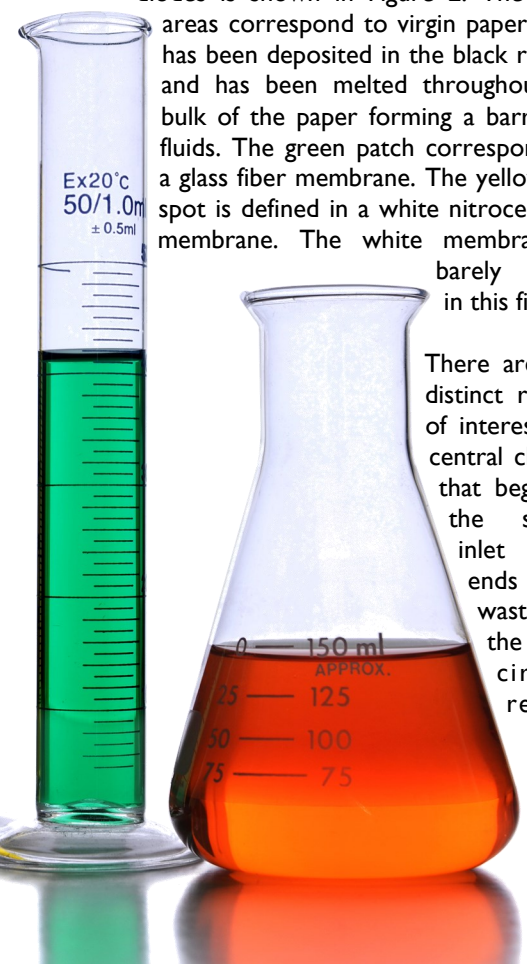


Figure 1: (a) Schematic cross-sectional view of a fluid actuated fluidic diode or valve. (b) Valve symbol. (Image courtesy of Constantine Anagnostopoulos and Mohammad Faghri/ Released)

devices are based on the invention of a fluid-actuated microfluidic diode, or valve that is built in paper. [8,9,10] Figure 1 shows a schematic drawing of the diode. The left side shows a simplified cross-sectional view consisting of two layers of paper separated by a layer of double sided tape. A hole is punched in the tape ahead of time and two discs, both made of paper, are placed in the hole. The hydrophobic disc soaked in a solution containing Allyltrichlorosilane renders its fibers hydrophobic but the disk remains porous. The hydrophilic disc is infused with Tween 20 surfactant. A symbol of the paper-based microfluidic valve is shown in the right side of the figure.

In operation, if the fluid approaches the diode from the forward direction, it dissolves the surfactant, which goes into the hydrophobic area and renders the fibers hydrophilic again. If the fluid approaches from the reverse direction, it faces a hydrophobic region and cannot penetrate it. However, unlike electrical diodes, once the diode is bridged, it allows fluid to flow in both directions.

A drawing of the top view of one paper-based lateral flow device utilizing fluidic diodes is shown in Figure 2. The white areas correspond to virgin paper. Wax has been deposited in the black regions and has been melted throughout the bulk of the paper forming a barrier to fluids. The green patch corresponds to a glass fiber membrane. The yellow test spot is defined in a white nitrocellulose membrane. The white membrane is barely visible in this figure.



There are four distinct regions of interest: the central channel that begins at the sample inlet and ends at the waste pad, the two circular regions marked Reagent 1 Inlet and Reagent 2 Inlet; and the waste pad. Conventional test strips, like the home pregnancy test, consist only of the central channel. The device in Figure 2 is capable of conducting several different kinds of assays, including one of the most common diagnostic tests called Enzyme Linked Immunosorbent Assay. A schematic representation of an ELISA protocol for the detection of Rabbit IgG on our paper-based device is shown in Figure 3. An equivalent fluidic circuit of the chip of Figure 2 is shown in Figure 4. IgG stands for immunoglobulin G and is an antibody. In this case IgG was generated by a rabbit's immune system. It is a benchmark biomarker, which is one that is used by many researchers so they can compare their results to others.

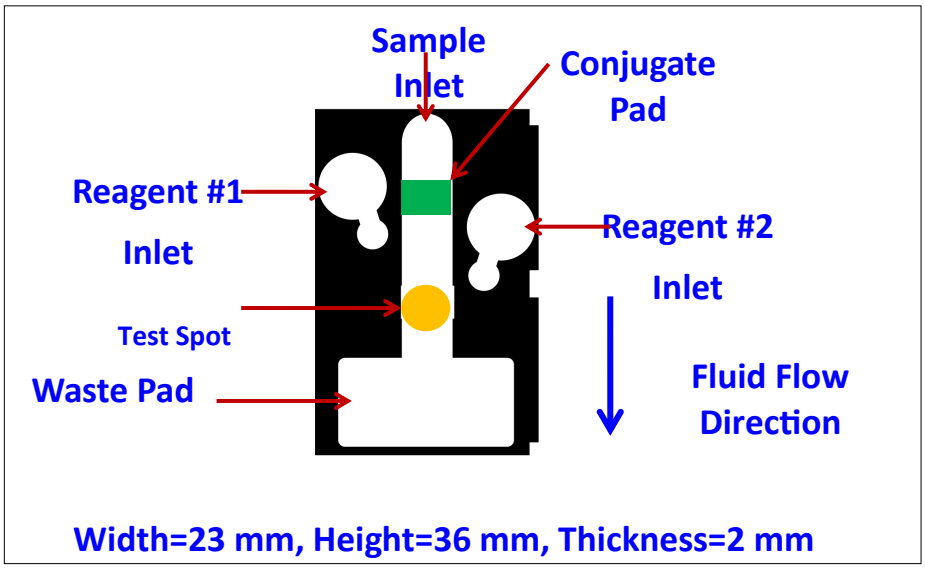


Figure 2: Top view of the new paper-based lateral flow device with fluid management. (Image courtesy of Constantine Anagnostopoulos and Mohammad Faghri/Released)

To conduct the Rabbit IgG test, first Reagents 1 and 2 are preloaded on their respective inlets. This can be done at the factory at the time the devices are made so the user does not have to load them at the time of the test. Reagent 1 is a wash solution, typically phosphate-buffered saline, which is a buffer solution commonly used in biological research. It is a water-based salt solution containing sodium phosphate, sodium chloride and, in some formulations, potassium chloride and potassium phosphate. Reagent 2 is the substrate BCIP/NBT. Also at the time the devices are made, detection antibodies are dried on the conjugate pad. The antibodies are monoclonal mouse anti-Rabbit IgG, which are specific to Rabbit IgG and are tagged with the enzyme Alkaline Phosphatase. And in the nitrocellulose membrane, the test spot is defined by placing a drop of fluid also containing monoclonal mouse anti-Rabbit IgG antibodies and allowed to dry. Because of the nature of the nitrocellulose membrane, these antibodies are immobilized in the spot where they were deposited.

At the time of the test, the user applies the sample at the sample inlet. Some of this fluid travels down the central channel where it picks up detection antibodies from the conjugate pad. The conjugates antigen+detection antibody+enzyme are formed and they continue flowing toward the test spot. As they flow over the test spot, the antigens are captured by the immobilized capture antibodies forming complexes, or sandwiches, of capture antibody+antigen+detection antibody+enzyme. This is demonstrated schematically in Step 3 on Figure 3.

A portion of the sample fluid flows in a channel below the surface, not visible in Figure 2, but shown as Delay Channel 1 of Figure 4. It reaches below Reagent 1, turns on the valves and activates its flow. In the assay described in Figure 3 this reagent is a simple wash solution. It flows into the central channel and its function is to remove any of the conjugates not properly anchored in the test spot, which

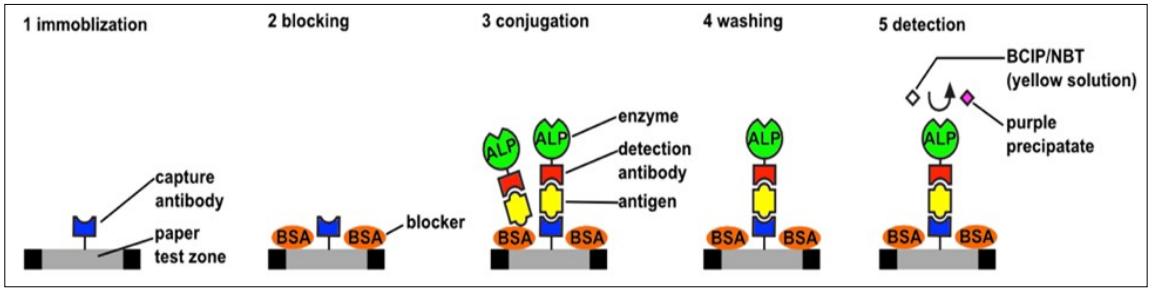


Figure 3: Schematic of the ELISA protocol for the detection of Rabbit IgG on our lab-on-paper device. (Image courtesy of Constantine Anagnostopoulos and Mohammad Faghri/ Released)

is shown schematically as Step 4 in Figure 3. A portion of the sample fluid and wash solutions flow via another channel below the surface, designated as Delay Channel 2 in Figure 4, reaches Reagent 2 and activates its flow. Reagent 2 is the substrate and its function is to interact with the ALP enzymes that are on top of the complexes in the test spot and produce colored molecules that precipitate near the test spot and are visible. These precipitates constitute the signal. This is Step 5 in Figure 3.

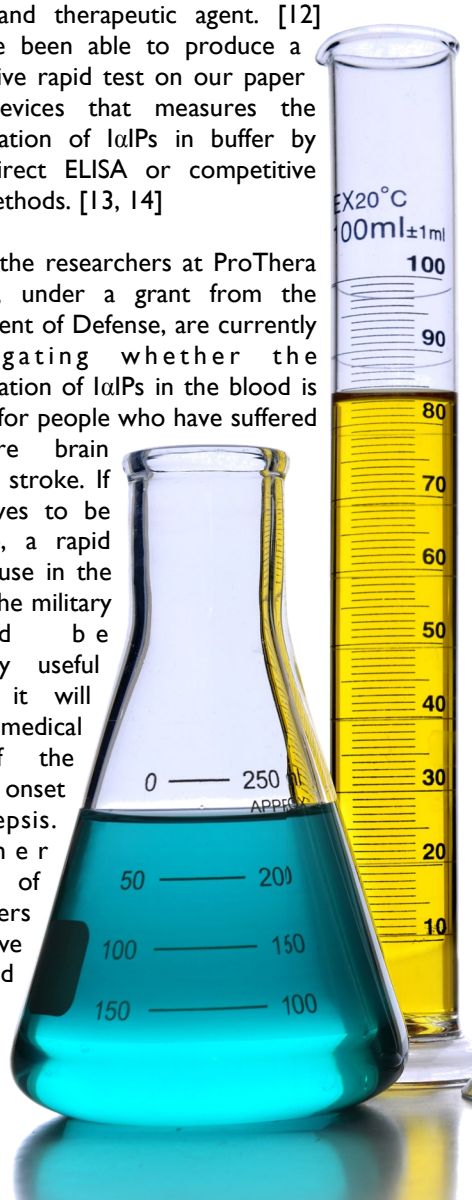
By conducting this assay with samples containing different concentrations of Rabbit IgG, we have obtained a dose response or standard curve for our system. The curve is shown in the left side of Figure 5. The limit of detection was about 4.7ng/ml, which is similar to what is obtained in conventional ELISA tests using microtiter plates. The right side shows two chips at the end of the assay. In the top one, the test spot was obtained for an IgG concentration of 0.1µg/ml and the bottom one, the IgG concentration in the sample was 1µg/ml. The darkness of the spots correspond to the signal and it is seen that in the bottom chip the test spot is much darker than the spot on the top chip, as expected.

The work reported above helped prove that these new devices can conduct ELISA autonomously. The ability to conduct assays autonomously is a big advantage when the tests are conducted outside a laboratory environment and by people who are not highly trained in laboratory procedures. In addition, ELISA is capable of higher sensitivity compared to test strips that use gold or other colored nanoparticles. This is because ELISA amplifies the signal since enzymes keep producing a color product as long as substrate molecules come in contact with them. The higher sensitivity means lower concentrations of an antigen can be detected. Finally, ELISA is a ubiquitous technique and has been used to detect many different kinds of molecules, including hydrocarbons or other contaminants in water, chemical warfare agents and more. It is expected that the standard ELISA protocols for these molecules can be transcribed for our paper-based devices, as it was shown schematically in Figure 3 for Rabbit IgG. Finally, ELISA provides not only yes/no results but quantitative data as well. This requires the color intensity of the test spots be measured and compared to the intensity in the appropriate standard curve, such as the one shown in Figure 5, from where the unknown concentration of an antigen or analyte in a sample can be determined. Presently, apps in smart phones or small units are capable of conducting these measurements with the added bonus that the data can be transmitted to health care or other professionals for evaluation or diagnosis.

To demonstrate that a conventional ELISA protocol can be transcribed for our paper-based devices, we collaborated with a local biotech start-up, ProThera Biologics, to detect a protein called Inter Alpha Inhibitor Protein (IαIP). [11] IαIPs are natural serine protease inhibitors found in human plasma at a relatively high concentration ranging between 400 – 800 αg/mL. IαIPs are part of the body's protective mechanism that modulates host response to pathological insults. Circulating IαIP levels are significantly decreased in adult and neonatal sepsis. The total IαIP levels correlate inversely with the mortality rate in adult patients with severe sepsis. It is known that IαIPs, as part of the innate immune response, protect against acute, systemic inflammation following severe bacterial or viral infections, such as those resulting from septic shock or dengue shock syndrome. As a consequence, these proteins are rapidly consumed and excreted in the urine, leading to a rapid decrease in plasma levels. Moreover, in several adult and newborn animal models of sepsis as well as anthrax intoxication and infection, IαIP replacement therapy has been demonstrated to reverse the decrease in system levels, thereby significantly reducing sepsis related mortality. Since IαIP replacement therapy has been demonstrated to be beneficial in sepsis and anthrax infection, IαIP has great potential both as a predictive marker and therapeutic agent. [12]

We have been able to produce a quantitative rapid test on our paper based devices that measures the concentration of IαIPs in buffer by either direct ELISA or competitive ELISA methods. [13, 14]

Further, the researchers at ProThera Biologics, under a grant from the Department of Defense, are currently investigating whether the concentration of IαIPs in the blood is reduced for people who have suffered a severe brain injury or stroke. If this proves to be the case, a rapid test for use in the field by the military would be extremely useful because it will alert the medical staff of the possible onset of sepsis. Another group of researchers [15] have identified



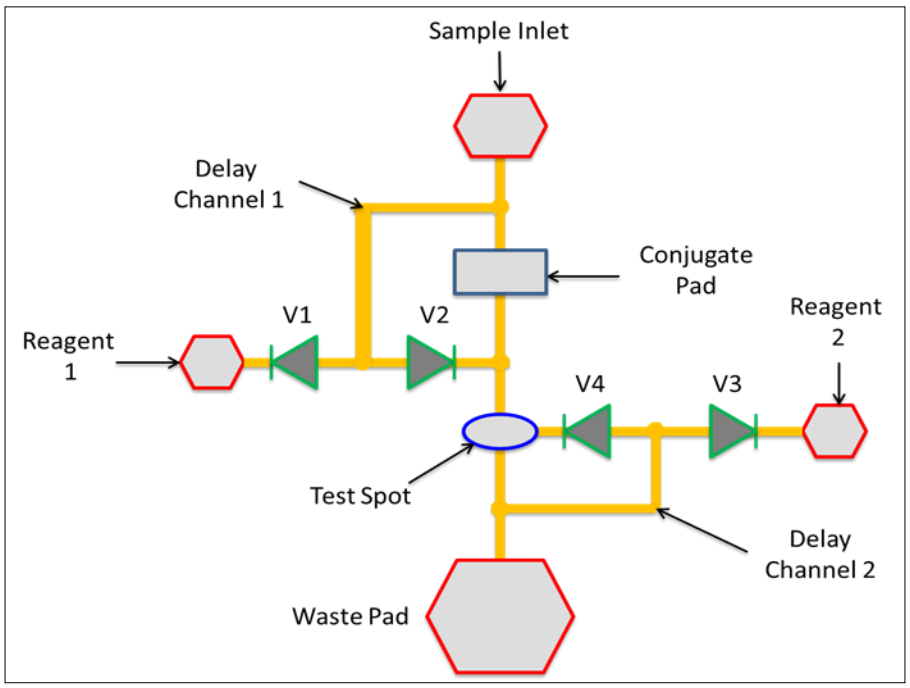
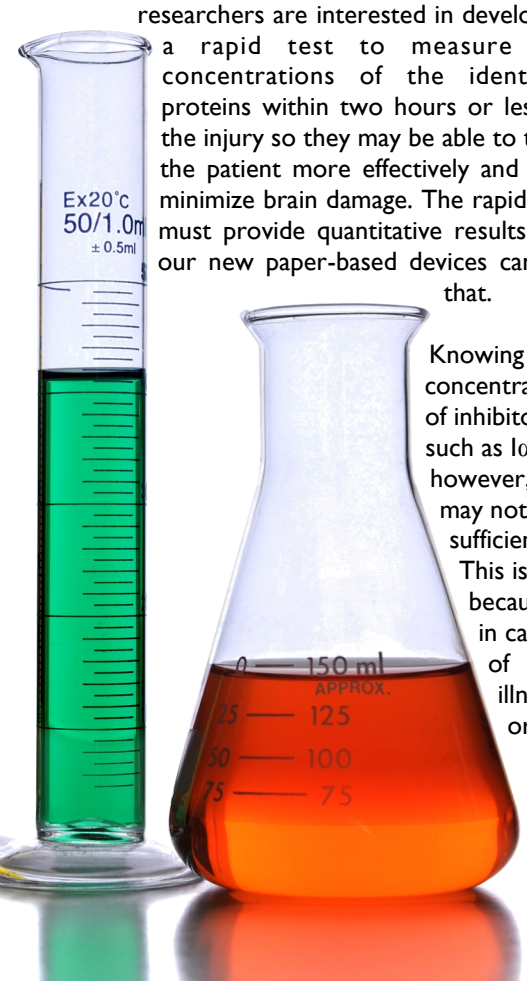


Figure 4: Equivalent fluidic circuit diagram for the device in Figure 2. (Image courtesy of Constantine Anagnostopoulos and Mohammad Faghri/Released)

biomarkers in the blood that can determine the level of brain damage a soldier or athlete may have suffered from a blow to the head. Up until now, concussion diagnosis has been limited to cognitive measures that can be subjective. These researchers are interested in developing a rapid test to measure the concentrations of the identified proteins within two hours or less of the injury so they may be able to treat the patient more effectively and thus minimize brain damage. The rapid test must provide quantitative results and our new paper-based devices can do that.



Knowing the concentration of inhibitors such as IαIPs, however, may not be sufficient. This is because in case of illness or injury the quality of IαIPs may be impaired. Thus, while an ELISA or another sandwich assay may detect a certain concentration of IαIPs in the sample, the number of these proteins that are actually active may be considerably less. Experiments are being conducted on dual devices, where one device will measure the concentration of these proteins in the sample while simultaneously, and from the same sample, the second device will measure the activity levels of these inhibitors.

A much broader field, where knowing at the same time the concentrations as well as the activity levels of enzymes and inhibitors is important, is in the areas of hemostasis and thrombosis. In these cases, enzymes help to form clots in the event of an injury to stop the bleeding while simultaneously inhibitors deactivate the enzymes to prevent them from forming large blood clots that could break off and result in thrombosis. These types of assays, however, cannot be done autonomously by the conventional paper-based lateral flow test strips because they can handle only one reagent while these tests require a minimum of two reagents, which our paper-based devices can manage easily.

Finally, one area of interest to the military is the accurate diagnosis of dengue virus infection. Dengue represents an ongoing global health problem, with an estimated 390 million infections per year and complicates deployment of U.S. military personnel to hot spots including Southeast Asia and the Middle East. [16] Substantial efforts have been made in the development of diagnostic tests for detection of dengue during the acute illness phase. Several commercial rapid diagnostic lateral flow assays are available for diagnostic testing outside the United States, mainly based on detection of the dengue virus NS1 protein in blood. Sensitivity of these commercial assays, however, is reported to be in the range of 60-80 percent, and is significantly lower in secondary dengue virus infections, which are associated with a higher risk of more severe disease. Further, current rapid diagnostic tests do not provide quantitative information to identify patients at higher risk for severe disease. The ability of these paper-based devices to conduct ELISA could meet the need of the military, and communities at large, for low cost, but higher sensitivity, rapid and quantitative diagnostic tests for dengue.

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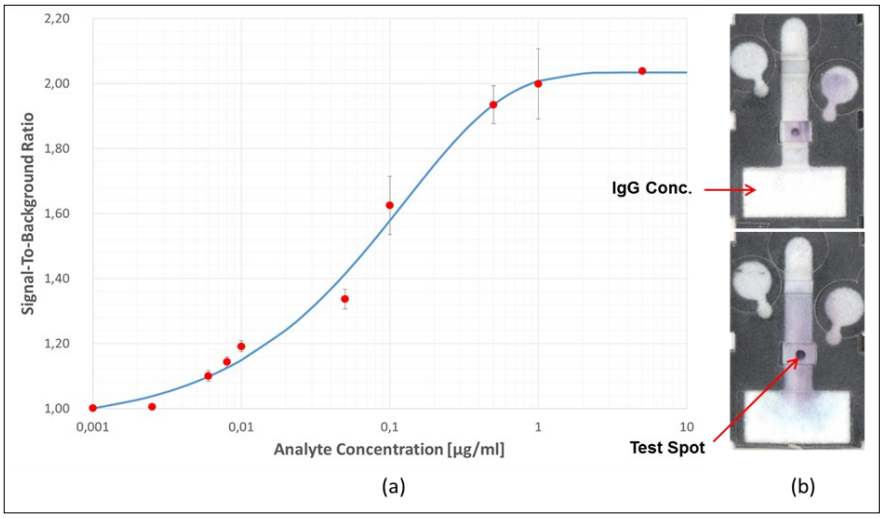

Figure 5: (a) Dose response curve for Rabbit IgG; (b) Photomicrographs of two chips after running ELISA. (Image courtesy of Constantine Anagnostopoulos and Mohammad Faghri/Released)

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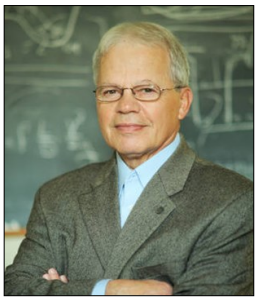
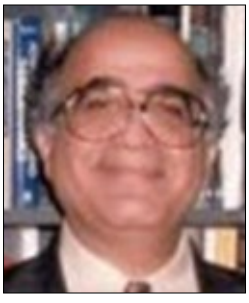


Constantine Anagnostopoulos, Ph.D., is an adjunct full professor at the University of Rhode Island working on lab-on-a-chip and lab-on-paper platform technologies. Before joining the microfluidic laboratory, he worked at the research and development laboratories of the Eastman Kodak Company, leading research teams focusing on inventing, maturing and finally moving ideas to products. He is on more than 70 U.S. patents and published more than 50 papers in peer-reviewed journals. He founded Labonachip, LLC to commercialize the lab-on-a-chip and lab-on-paper technologies.



Mohammad Faghri, Ph.D., is a professor of mechanical engineering at the University of Rhode Island. He is known for his work in microfluidics, lab-on-paper and lab-on-a-chip technologies. He has published more than 200 articles in peer reviewed journals and authored seven books. Dr. Faghri has received numerous awards for his scientific contributions as well as several grants. His research interest has been on bio-micro-electrical-mechanical systems with applications for development of a lab-on-a-chip and lab-on-paper devices for point-of-care diagnostics.

A FIRST LOOK:
Disaster Management Challenges in Lagos, Nigeria

By: Douglas E. Batson
Approved for Public Release 15-341

Introduction

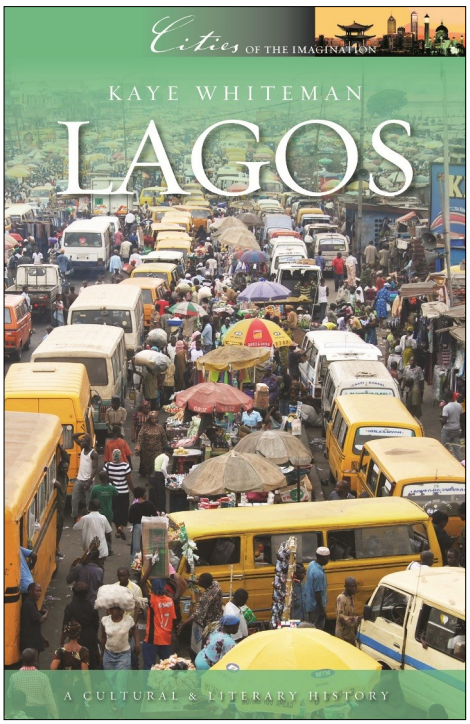
According to geostrategist David Kilcullen, the next big conflict will be "urban, connected, and littoral" with adversaries, friends and neutrals exhibiting hybrid state and non-state characteristics. [1] The U.S. military will likely be involved in humanitarian or operational missions in megacities across the globe.

A disaster occurring in Lagos, Nigeria, where more than half of an estimated 20 million people live in alternately-governed slums, not only fits this description, but it would also create a scene unprecedented in its scale of devastation and confusion. [2] This study aids military planners and first responders to adapt to parts of Lagos transformed by crisis into Black Spots, a term coined by Bartos Stanislawski to denote areas "outside of effective governmental control and controlled, instead, by alternative, mostly illicit, social structures." [3, 4] Yet, not all non-state actors are nefarious. U.S. Army Maj. Arnel David suggests that databases of local non-governmental organizations where emergencies might arise should be maintained because their assistance could significantly contribute to mission success. He further opines that "enhanced engagements and cooperation with civil society organizations increase connectivity to the local populace and create a potential capability to leverage local knowledge"; yet "military use of civilian networks in this capacity has not been explored." [5] David's thesis articulates why this study is significant in bridging a strategic knowledge gap about non-state actors' roles and capacities in megacity disaster management. [6]

Background and Literature Review

Worldwide, rapid urbanization has attracted attention from various scholars. Urban populations greater than 10 million constitute the United Nations definition of a megacity. [7] Using the same population threshold, this study holds to a theory of mega-global city divergence between global cities, chiefly located in the North that coordinate complex global economic activity, and megacities, primarily located in the South with few global functions but many informal settlements (a euphemism for slums). [8] While mass urbanization elicits praise from economists for creating scores of better educated, middle class consumers, it draws ire from environmentalists over grave risks from uncontrolled and unsustainable growth. Anglophone Lagos, the economic engine of West Africa, makes an excellent case study because of its 8 percent annual growth rate, dense population and vulnerable physical geography. [9] There, numerous informal settlements ring a low-lying lagoon; thus its name from the Portuguese *lago,* Lagos. [10] Flooding in recent years has reached devastating proportions and Lagos' slum dwellers have borne the brunt of "heavy rainfall combined with rising sea levels, sinking sand-filled water spaces and inadequate drainage systems." [11, 12] Rem Koolhaas and his fellow urbanists pointed to Lagos' pervasive informality in housing, economy and security as a future archetype where megacity populations organize themselves apart from the state. This view informed questions posed by the German authors of the *Megacity Resilience Framework*, which, in turn, prompted this study of disaster management in the Nigerian megacity.

Can people rely on functioning formal institutions in case of disturbances, for instance on disaster management, relief and recovery implemented by state or city authorities in case of a natural disaster? Or do they mainly have to organize help themselves and trust in their membership in social networks to reduce their losses in such an event and secure their livelihoods thereafter? [14]



Lagos' mega traffic jams. (Image courtesy of Signal Books, Oxford, U.K./ Released)

Megacities are a recent phenomenon; the term entered the literature in the late 1980s. Given the myriad of factors surrounding megacity growth and sustainability, literature is divided between the optimistic (Kalan, [15] Kourtit and Nijkamp, [16] Glaeser, [17] Khanna [18] and Barber [19]) and the ominous (Davis, [20] Castells, [21] Pieterse [22] and Setchell [23]). The over-attention to human distemper in the gloomier works,

Urban populations greater than 10 million constitute the United Nations' definition of a megacity.

however, ignores the communal resiliency that belies the optimistic versus ominous dichotomy. The latter works seem to disregard how, in a 1990s Second Liberation of the African continent, an evolving civil society was instrumental in ousting dictators and military juntas and ushering in more democratization and development. [24] Civil society is defined here as a sphere of social life that is public, but excludes government and private business activities. [25]

Urbanization in sub-Saharan Africa has worked against consolidation of state power. As a result, its informal settlements are replete with alternatively governed spaces featuring informal policing, administration of justice and mechanisms of social control. [26] Loren Landau, director of the African Center for Migration and Society, asserts that the Africanized urban governance phenomenon is "a form of polity that we have yet to name, let alone understand." [27] U.S. military planners are only now beginning to think about humanitarian assistance/disaster response missions in densely-populated urban areas outside the control of host nation government. [28] Moreover, U.S. intelligence community analytical portfolios are not focused on cities, even when their populations and gross domestic products are greater than many nation states. [29] To counter this lack of actionable intelligence, some, like Maj. David, call for U.S. Army stability teams in megacities to gather data on the flows of people, materials and ideas. However, it remains highly improbable that U.S. regionally aligned forces, with Boko Haram terrorism, the Ebola virus, piracy in the Gulf of Guinea and a host of security assistance difficulties to contend with, would commit resources to the comparatively stable Lagos' impalpable *informal register*. [30]

Lagos in Context

While smallest in area, and no longer the seat of the national capital, Lagos is by far the most populous and progressive state among Nigeria's 36 federated states. Lagos State, 85 percent urban and thus synonymous with the megacity, receives 6,000 new migrants daily. This "turbo urbanization" has quadrupled Lagos' population since 1980. [31, 32] Scientists from the International Union of Geological Sciences reported the sheer scale of megacities "creates new dynamics, new complexity and new simultaneity of events and processes—physical, social and economic; [and] they host intense and complex interactions between different demographic, social, political, economic and ecological processes." [33] The multiplicity of relationships, their uncharted flows, connectedness and contexts frustrates efforts to understand the Nigerian primate city as an operating environment. Just as *byzantine* connotes a situation encumbered by laborious administrative detail, a term introduced here, *lagosian*, embodies Edgar Pieterse's concept of the informal register at the megacity scale. *Lagosian* suggests a milieu of institutions, so loosely integrated, and of power and authority brokers, so diffuse as to defy governance. Yet Lagos functions surprisingly well and boasts many recent infrastructural and administrative advances. Indeed, the Lagos State slogan under current Governor Babatunde Fashola is, in the Yoruba language, *Eko O Ni Baje* or *Lagos Must Not Spoil*. Fashola has affected significant positive change, generating the necessary revenues to fund his vision of Lagos becoming a global city. This includes Eko Atlantic, a highly-visible land reclamation project ordained to become the glitzy new financial center of West Africa. [35] However, Eko (an old Yoruba name for Lagos) Atlantic is not without its detractors who cite its negative impacts on the environment and vulnerable communities or denounce the purely elitist nature of the project. [36]

If Lagos is not to spoil, it stands to reason that its gains must be protected. To that end, coinciding with the return of civilian rule, the Nigerian Emergency Management Agency was founded in 1999, followed by state-level agencies like the Lagos State Emergency Management Agency. In Lagos State, Nigeria's showcase for development, LASEMA conducts a range of disaster management services, from prevention and preparedness, to mitigation, recovery and relief. [37] However, its critics have derided the emergency response as "neither coordinated nor prompt enough and this has resulted in large-scale destruction and suffering of the affected people." [38] Despite its shortcomings in disaster management and other services, Lagos' comparative stability marks it as the destination of choice for West African migrants. [39]

In governance research on Africa, scholars have overwhelmingly concentrated not only on nation states as opposed to cities, but on obstacles to state-building rather than on prospects or methods for improving service provision. For that

An artist's conception of the future Eko Atlantic complex. (Copyright EkoAtlantic.com 2014/Released)

Figure 1: Survey Respondents' Organizations Classified into Five Civil Society Roles. [40] Figure 1 reflects, from 50 survey responses, the percentages among five civil society roles to which the respondents self-assigned their respective organizations.

reason, this study focuses on affected norms of Lagosian civil society organizations that might partner in disaster management rather than bureaucratic norms of public agencies. While a very small sample size limits generalizations, survey responses and personal interviews identify and sort CSOs into the five activity rubrics that make their potential roles as implementing partners in Lagosian disaster management more comprehensible.

Local Government Challenges

Vulnerability to natural hazards has been cited as a rationale by the Lagos State government to forcibly evict slum dwellers, ostensibly from flood-prone areas, often only to have a shopping mall or other development constructed on the same land. CSOs that advocate for Lagos' poor, and the poor themselves, are prone to view investigations by strangers in informal settlements with suspicion. Given a pejorative CSO appraisal of the Nigerian government's preparedness for disaster response, this study sought to dispassionately study the situation by also interviewing representatives from the NEMA Southwest Regional Office in Lagos and LASEMA. All offered positive views of their agencies' respective disaster management capacities; as government officials, this bias is expected.

The NEMA representatives were very eager to talk about their education curricula in Nigerian schools and training for three tiers of public volunteers. In addition to the university graduates who owe national service time and professional volunteers, such as civil engineers and medical doctors, they opined that many of their disaster management implementation challenges, namely, a lack of resources, will be addressed by a third tier of grassroots emergency volunteers to number more than 150,000. [41] They were less forthcoming to questions about disaster risk reduction plans, vulnerability and capability analysis and publications in local languages other than English. For each perceived shortcoming, they either cited a lack of funding or shunted responsibility to LASEMA, which are likely legitimate responses except for the lack of local area maps for Local Government Areas or their constituent wards. Based on the survey results, personal interviews with the CSOs most often mentioned as having capacity to assist with disaster management were requested. Although many declined, representatives from eight CSOs agreed to be interviewed in Lagos during June 2014:

- **Center for Public Policy Alternatives** (think tank)
- **Community Development Association**
- **The Christian Association of Nigeria** (interdenominational)
- **Organization for Non-formal Education Foundation** (Islamic)
- **Social and Economic Rights Action Centre**
- **The CLEEN Foundation** (justice sector reform)
- **Justice Development Peace Commission** (Catholic)
- **Arctic Infrastructure** (urban development, sustainable design)

Interviewees' answers to Question 3: What disaster management-related public awareness and education efforts of a government institution are you aware of?

- "Lagos is the only place in Nigeria where no one asks or cares about where a newcomer is from; people come and go all the time. The government cannot properly categorize or count the population, much less control it for [disaster management]."
- "Local government is so corrupt that anyone willing to join or partner with it will be co-opted by oil money. No parishioner in my church wants anything to do with local government."
- "The government's arbitrary demolition of slum communities demonstrates the political denial of how many people are affected. For this same reason, you will never get maps of these areas."
- "If strangers came here with GPS and began community mapping as you suggest, a chief will send his thugs to take the device away and beat the strangers up. The police and chiefs personally benefit from the status quo."
- "Lagos is a weak state; the proof is that the government channels services via clientelistic networks and not for the broader public good."
- "Corruption is endemic in local government; this discourages outright compliance with any new regulation, to include even important ones like [disaster management]."
- "Local government gets oil money from the top and for that reason has no incentive to build up from the bottom where [disaster management] is of concern."

The five question interview guide is in the Appendix.

Although anything but sympathetic, several interviewees expressed the importance of understanding particular disaster management challenges local governments face in Lagos. First, Nigerian police are only organized at the federal level. Police officers are frequently rotated in Lagos in an effort to keep them from becoming too cozy with and/or co-opted by local elites. This assignment approach, while perhaps

The author discusses his survey results in Lagos with fellows from the Center for Public Policy Alternatives. (Photo provided by Douglas Batson/Released)

reducing a degree of corruption, hinders development of local knowledge for improving public safety. Moreover, the CSOs stated the local governments suffer from systemic corruption with little to no capacity, resources, political will or incentive to provide basic services. They also stated that Lagos' recent progress in infrastructure and service delivery has been orchestrated at the state level. Given the pressing day-to-day survival needs for millions of Lagosians, e.g., clean water, sanitation, decent housing and employment, the CSO representatives conceded to some understanding of why disaster management does not rank high on local government agendas.

In summary, the interviewees did not (or chose not to) cite a single example of what they agreed should be the easiest disaster management function because of its low cost, i.e., public awareness and education in their respective local government areas. When it was mentioned that NEMA officials gave out their disaster risk reduction brochures and fact sheets, including one on its more than 150,000 grassroots volunteers, the CSO representatives were unanimously dismissive of it as a public relations ploy. None had personally witnessed any emergency drills or seen any NEMA volunteers. The emergent theme from Question 3 was not the efficacy of any one government-led disaster mitigation effort, but a fixation on government indifference to disaster management.

Internal Challenges of CSOs

The concept of Lagosian civil society is often opaque. Thus, the following CSO groups, categorized by Darren Kew, based on eras of their founding in Nigeria, are very useful: 1) the longstanding traditional and religious leaders; 2) trade, student and professional unions established after independence in 1960; and 3) a bevy of rights-and-welfare-advocating NGOs founded since 1999. [42] For Question 4: What can your CSO do to improve disaster management?, the eight interviewees had trouble staying on topic. Their responses drifted into the range and positive impacts of their organizations' activities, even if these were far removed from disaster management. Still, the interviewees related one overarching theme about the internal challenges Lagosian civil society faces regarding disaster management, its near hopeless fragmentation. The quotes below help explain the rampant pessimism.

- *"Authority in the slums is held by traditional leaders with their own brand of patronage politics, informal policing, rules and regulation. External initiation of something new (like [disaster management]) is immediately viewed as subverting the traditional leader's authority."*
- *"Then there is the 'God factor.' The believers confuse faith with presumption; they do not believe that disasters will fall upon them; [disaster management], for many, shows a lack of faith."*
- *"People mostly affiliate with traditional and religious organizations that in no way engender trust between these groups or foster a common future together."*
- *"So many people, men, and women, too, work in the city to sustain families back in their home villages; their roots are not in the city so they are not bound to other people or the locality."*

The interviewees agreed that disaster management education and awareness training may seem like a promising shared goal around which CSOs might coalesce, but it is unlikely to occur prior to a cataclysmic event. To support this view, they cited several reasons all related to a terribly fragmented and clientelistic civil society. First, few Lagosians see themselves as stakeholders in public matters. This includes slum dwellers who view themselves as temporary workers with one foot in the megacity and the other in their rural homeland; those that believe their faith, ethnic or kinship group will care for them in a crisis; or that just focus on eking out a living. Second, even if Lagosians wanted to safeguard their homes against floods, it is unclear to the politically marginalized poor who wields the power and authority to institute disaster management protocols. Third, change requires leadership committed to affecting it. However, Lagos' poor masses chiefly depend on patronage networks to obtain basic services, so both the formal and informal actors who directly provide or influence service provision (e.g. security, jobs and housing) are more concerned with cementing themselves in positions of power that bestow prestige and profit than working for the public good. Traditional rulers in informal settlements, the very civil society actors

needed to champion disaster management, resist altering the status quo.

Local Government and CSOs—Challenges of Working Together for Disaster Management

The challenges in instituting coherent disaster management in the megacity of Lagos might be incrementally overcome by cooperation between local government and CSOs. However, even the high stakes of catastrophic loss in lives and property do not surmount the lack of trust between the two spheres. Because local governments are not autonomous from patronage networks, a lack of legitimacy and social linkages impedes public compliance with imposed rules and regulations. That view first assumes government capacity for disaster management exists. The 2008 establishment of LASEMA demonstrated political will to improve this service provision. The Lagos State motto is *Centre of Excellence*, and LASEMA's human, equipment, regulatory and fiscal resources for disaster management are a marked improvement over the once feral city's woeful state of preparedness a decade ago. Nevertheless, successful disaster management hinges on positive relationships between government and society. The interview quotes from Question 5: How are CSOs suited for partnering with government to improve disaster management? indicate a very troubled relationship.

- *"Community Development Associations become irrelevant in a crisis; churches and mosques are secondary. Local chiefs, vigilante groups, market women, etc., are primary to ensure public safety."*
- *"For [disaster management], we cannot depend on municipal clerks to keep accurate records. Community knowledge must reside within the community. [Disaster management] should be within the domain of civil society."*
- *"Religious institutions have enjoyed more freedoms from government than other CSOs. Our people view church membership as protection from government. Civic engagement has not been encouraged."*
- *"Obligations to traditional and religious groups are counterproductive to working with local government."*
- *"Government first needs to create a framework for CSO participation in [disaster management]. There is currently no platform for dialogue."*
- *"Vigilante gangs make neighborhoods safe, not the police. The police problematic impede the state-CSO cooperation you are looking for. What should be consistent Rule of Law and security from the State is anything but that."*
- *"In the event of a catastrophe, first responders would first look to their own families' welfare and not report to work, or would be unable to get to work due to streets blocked by flood waters."*

The CSO representatives were convinced that the government is wary of working with them because of their prowess as watchdogs against corruption and mismanagement. Some claimed the government views them as agitators, quick to protest, strike and take matters into their own hands, not constructive partners. According to the CLEEN Foundation (a justice sector reform non-governmental organization) representative, even in rich societies, the public sector alone cannot care for millions of peoples' welfare when Lagosian traditional rulers' basic duties include safeguarding and preserving public properties in their domains, protecting the rights of vulnerable populations and disseminating information. In fact, the representative stated, "CSOs should be government's most sought after [disaster management] partners because their efforts directly reduce costs to government and bring about the desired social compliance." He touted CSOs as trusted agents in community record keeping; noting that even poor communities can do a lot to verify and communicate information, integrate local values into decision-making and combine local knowledge with government data for hazard mapping.

The Social and Economic Rights Action Center (a rights and welfare-based non-governmental organization) representative declared government news releases and websites that extol disaster risk reduction progress cannot be taken seriously when the government does not even publish neighborhood maps as a first step in assigning its volunteers, or anyone else, areas of disaster management responsibility. Furthermore, the lack of neighborhood maps makes it convenient for the government to deny the severity of the problems caused by slum proliferation. He was pleased to note that SERAC is partnering with Slum/Shack Dwellers International in order to expand SDI's 7,000 slum profile maps to Nigeria. [43] He also lauded Map Kibera's work in Nairobi, Kenya, as an example of desired slum community mapping outcomes. [44]

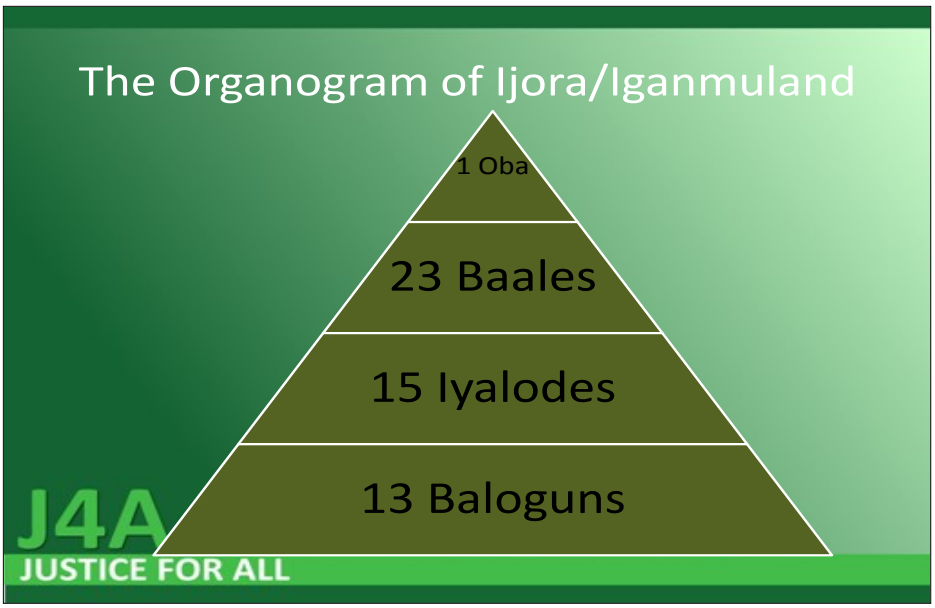


Figure 2: Traditional Leader Organogram. This depicts the informal power hierarchy in the Ijora ward of the city. It is fully described in the Appendix. (Released)

This paper has oft cited the role of the poor, but the Lagosian elite also have a critical role to play in bridging the divide between government and CSOs in disaster management.

Concentrations of people, resources and innovative ideas in cities tend to increase living standards. Lagos is no exception and is witnessing the rise of a huge middle class whose interests, along with those of the wealthy elite, are tied to state-led disaster management that leverages the contributions of willing and capable CSO partners. Despite its problems, Lagos has experienced impressive economic growth and livelihood gains to risk it all on continuing a dysfunctional state-CSO dynamic. Lagos truly has become too big to fail.

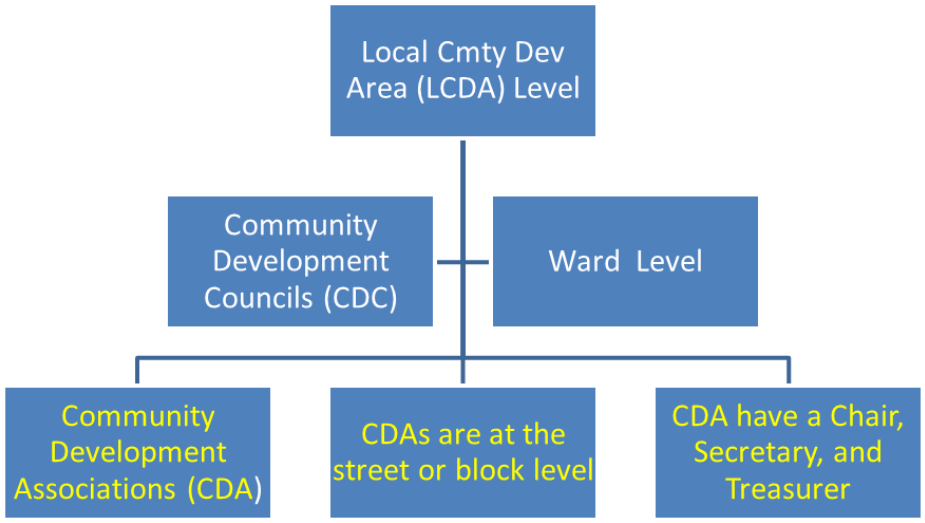


Figure 3: Local Council Development Area/Community Development Association Hierarchies.

Conclusions

The disaster management challenges in Lagos are as numerous as they are severe for both local government and civil society as well as U.S. military and humanitarian forces that would be called to intervene. Understanding and preparing for disasters with strategic forethought will enable the DoD to mitigate long-term risks and prevent the devolution of key societal structures. Challenges in Lagos can be applied to many other global megacities and classifying the major social, governmental and security components of any megacity is a necessity.

In Lagos, the most formidable challenge is overcoming the mistrust that precludes cooperation between the two spheres. Lagos, for all its recent progress, remains a fragile, flood-prone home to 20 million people. Given the high stakes, disaster management offers an auspicious issue to bridge the gulf between local government and CSOs. Of this study's eight civil society interviewees, three stated the survey questions alone had raised their awareness that partnership with local government in disaster management matters is critical to Lagos' continued prosperity and peace.

This study suggests to international actors that, as a matter of policy, successful humanitarian relief and disaster response operations in megacities must leverage informal governance and security entities. The data collection of convenience in this study resulted in communication skewed toward Lagos-based NGOs. This study cautions operators, who, likewise, would be tempted to work exclusively with responsive and educated professionals rather than the larger and perhaps corruption-prone, less amenable sectors of Nigerian civil society. While trade unions and religious, ethnic and traditional institutions may lack state-of-the-art office technology and English language proficiency, they stand to be much more effective in mobilizing populations for disaster management-related collective action than recently-minted NGOs. The former's political muscle and clout with poorer populations are required to institute sound disaster management protocols. For example, at the neighborhood level, informal traditional rulers' decisions in justice and dispute resolution go nearly unquestioned; rarely is a case referred to the police or courts.

This study significantly adds community development associations to Kew's three civil society groups. Effective CDAs are essential for improved governance, and by extension, also disaster management, at the neighborhood level. CDAs elect officers who monitor and maintain local government-funded infrastructure projects and prioritize needs to community development councils at the ward level. Based on an interview with a CDA officer, the hierarchical graphic in Figure 3, which parallels the second (local community development area) and third order (ward) administrative divisions of government, was constructed.

Higher degrees of integration separate global cities from loosely-integrated megacities. Lagos' vehicle license plates boast Centre of Excellence; the city clearly aspires to move toward the former designation. An increasing number of stakeholders: government, businesses and a kaleidoscopic civil society are aware that Lagos' recent infrastructure and livelihood improvements require intentional safeguarding. The challenges to disaster management in Lagos are formidable but not insurmountable. Granted, local governments lack resources, but they have not looked to the growing capacities of civil society organizations to engage with even the most basic disaster management tenet of public education and awareness. Disaster management also bodes well to unify a fragmented Lagosian civil society whose informal governance activities help offset the lack of formal bureaucratic norms and municipal services. More local government political will and self-help efforts by disaster-prone populations would demonstrate disaster management as a high priority and facilitate integration of Lagos' vast polycentric governance systems. A promising starting point for improved cooperation between government and civil society is to enable

slum dwellers to map their own communities. As a navigation aid for international actors, this first look study has sorted an imposing Lagosian civil society into four groups and five activity rubrics and includes a comprehensive administrative map of the world's third largest city. It has narrowed a wide knowledge gap about the utterly *Lagosian* challenges of megacity disaster management. However, leviathan Lagos is much too large for a single study. Further research is needed on how the level of interaction between government and CSOs in distinct geographic areas leads to either an increase in a population's vulnerability or resilience in the face of disaster.

Appendix:
Interview Guide

- Question 1: Your CSO was named as potentially being of assistance in disaster management. What was your reaction to the online questions about CSO roles in disaster response?
- Question 2: Describe a recent disaster in Lagos that resulted in loss of life and/or property.
- Question 3: What disaster management-related public awareness and education efforts of a government institution are you aware of?
- Question 4: What can your CSO do to improve disaster management?
- Question 5: How are CSOs suited for partnering with the government to improve disaster management?

More on Figure 2: Traditional Leader Organogram

The Oba is referred to as His Royal Majesty, Ojora of Ijora and Iganmuland. He is the hereditary monarch with all the trappings of traditional authority, and his ruling house appoints him to occupy the throne. The Baales, Baloguns and the Iyalodes are the traditional agents appointed by the Ojora (Oba). They may not hold hereditary or lineage positions rather, they hold their positions only at the discretion of the Oba. They are accountable to the Oba for the exercise of their powers, including dispute resolutions in the community. Some of these traditional rulers' basic duties are to:

- Promote peace and stability in their domain
- Mediate and settle disputes, domestic and others
- Preserve customs and cultural values
- Safeguard and preserve public properties in their domain
- Disseminate information and sensitize the public
- Protect the rights of the vulnerable in the society
- Provide necessary information on matters relating to their jurisdiction
- Advise the government on customs, traditional matters and security issues

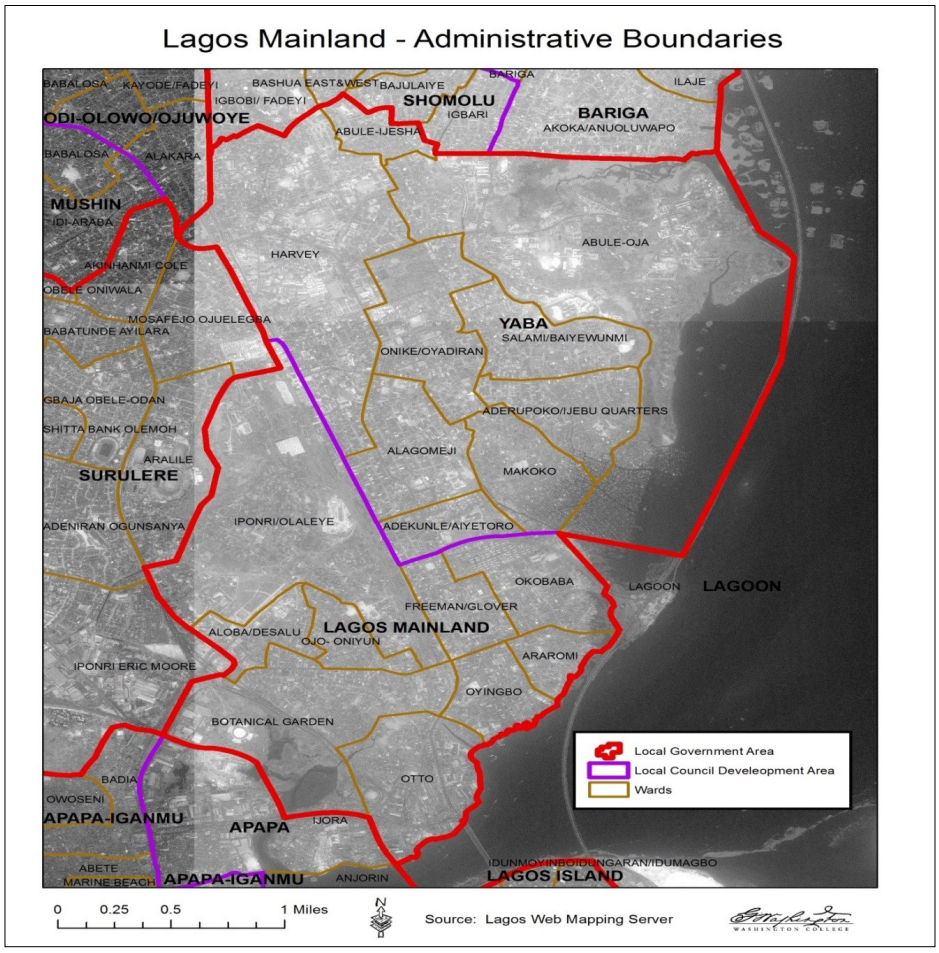


Figure 4: Administrative map of Lagos. Source by Washington College Students. (Copyright Digital Globe 2014/Released)

Lagos was made of 20 Local Government Areas. In 2007, the Lagos State Government subdivided the LGAs to create 37 additional second-order administrative divisions. However, the new second-order divisions are referred to not as LGAs, but as Local Council Development Areas. Because of state/federal political wrangling, the Local Community Development Areas do not appear on official Nigerian maps. For the past eight years, confusion abounds because the original 20 Local Government Areas place names, formerly covering all of Lagos State, could refer either to the original LGA or now the truncated geographic extent.

Via a Cooperative Research and Development Agreement between Washington College (Chestertown, Md.) and the National Geospatial-Intelligence Agency, the college's geographic information systems students produced a digital map from data provided by the Lagos State Independent Electoral Commission. This map image displays a portion of the de facto administrative structure, namely, Local Government Areas/Local Council Development Areas and their constituent ward boundaries. For example, Yaba Local Council Development Area was carved from the Lagos Mainland Local Government Area.

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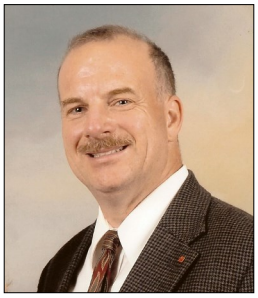

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Feeling through

By: Thierri Callier, Hannes P. Saal, Gregg A. Tabot, Sungshin Kim, Ph.D. & Sliman J. Bensmaia, Ph.D.

Introduction

Advances in battlefield trauma care and in body armor have led to an increase in the survival rates following injuries in the battlefield. Although body armor protects the torso and internal organs, soldiers remain vulnerable to limb loss and upper spinal cord injury. [1] Developments in prosthetics could further improve the quality of life of military and civilian amputees.

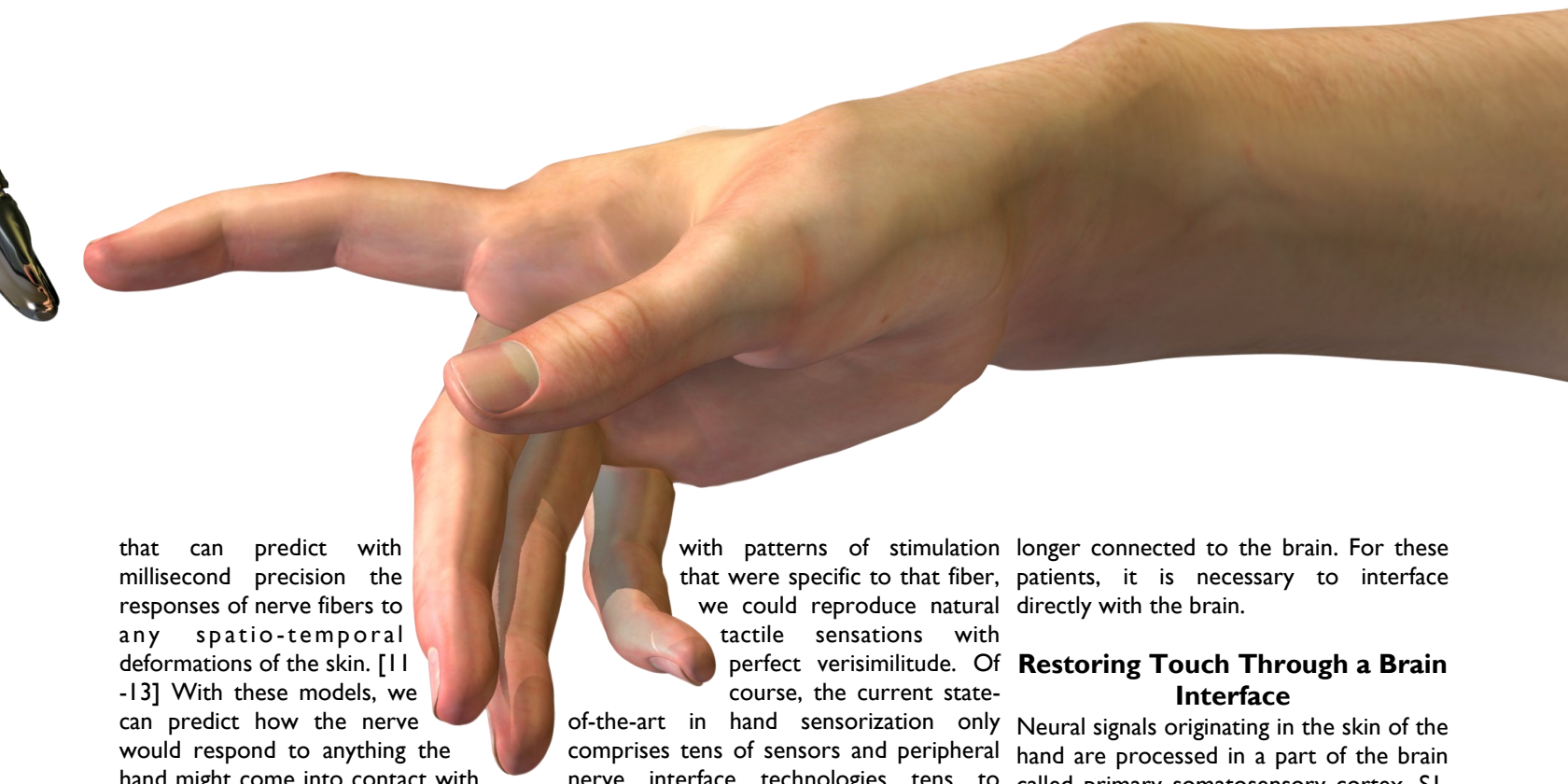
One way to restore sensorimotor function in amputees and tetraplegic patients is to equip them with robotic arms and devise ways for them to control these arms. In the last 20 years, powerful algorithms to decode intended movements from signals recorded from muscles or from the nervous system have been developed, as have robotic limbs that reproduce most of the functionality of native human arms. [2] However, our ability to manipulate objects relies heavily on our sense of touch. Without these sensory signals, we would struggle to perform even the most basic activities of daily living, like turning a door knob or picking up a coffee cup. For upper-limb neuroprostheses to be clinically viable, then, it is necessary to develop ways not only to convert neural signals about motor intent into movements of the prosthesis, but also to convey tactile feedback about the consequences of those movements [3] for example about how hard we are grasping an object.

State-of-the-art prosthetic arms can move in most of the ways a native human arm can move, and include a variety of different sensors that can, in principle, replace the biological sensors in the skin (so-called mechanoreceptors). [4] Researchers are developing algorithms that convert the output of these sensors into patterns of electrical stimulation of the nervous system that evoke meaningful and intuitive touch sensations. Some of our work focuses on restoring the sense of touch by stimulating the somatosensory nerves, which carry touch signals from the hand to the brain. [5] While this approach is promising for amputees, it cannot be applied to tetraplegic patients, for whom the nerves are dysfunctional or are no longer connected to the brain. For these patients, we are working on ways to convey sensory feedback by stimulating the somatosensory cortex, the part of the brain that receives and processes touch signals from the hand. [3, 6-8]

Restoring Touch Through a Peripheral Nerve Interface

Three types of nerve fibers relay tactile information from the hand to the brain, each of which responds differently to skin deformations. When we grasp and manipulate objects, all three populations of nerve fibers respond and convey overlapping information about the size, shape and texture of the objects and about their movements across the skin. [9] Importantly, if the skin is stimulated in exactly the same way, these fibers produce almost exactly the same response. [10] Exploiting the near deterministic nature of these neural responses, we have developed models

n a Bionic Hand



that can predict with millisecond precision the responses of nerve fibers to any spatio-temporal deformations of the skin. [11-13] With these models, we can predict how the nerve would respond to anything the hand might come into contact with. [14, 15]

A variety of technologies are being developed to interface directly with the peripheral nerve. [5] The idea is to use the models of nerve fiber responses described above to convert the output of the touch sensors on the prosthetic hand into desired patterns of nerve activation—those that would be observed in the native hand—and electrically stimulate the nerve to evoke these desired patterns using an electrical interface with the nerve. If the density and capabilities of the sensors on the prosthesis matched those of native mechanoreceptors and if we could concurrently stimulate individual nerve fibers, tens of thousands of them, with patterns of stimulation that were specific to that fiber, we could reproduce natural tactile sensations with perfect verisimilitude. Of course, the current state-of-the-art in hand sensorization only comprises tens of sensors and peripheral nerve interface technologies tens to hundreds of electrodes. The development effort consists in determining how we can create naturalistic patterns of nerve activation given the relatively small number of independent channels at our disposal. To this end, we seek to assess which aspects of nerve activation are critical to elicit meaningful tactile sensations and which are not.

The advantage of restoring touch through a peripheral nerve interface is that we have an advanced understanding of the relevant neural structures so the main challenge is a technological one. However, peripheral nerve interfaces cannot be applied to tetraplegic patients, whose nerves are either non-functional or no longer connected to the brain. For these patients, it is necessary to interface directly with the brain.

Restoring Touch Through a Brain Interface

Neural signals originating in the skin of the hand are processed in a part of the brain called primary somatosensory cortex, S1. [16] In a series of experiments, we have been investigating whether we can evoke meaningful tactile sensations by electrically stimulating neurons in S1. [3, 6, 7, 17, 18] We focused on trying to convey the most basic information necessary to grasp an object, namely information about contact location and contact pressure. Indeed, when we grasp an object, we need to know which parts of the hand are touching the object. To pick it up, the thumb and at least one of the fingers need to make contact with it. We also need to know how much pressure we are exerting on it. We want to exert enough pressure so as to not drop it but not so much pressure that we might crush it. In a series of experiments with monkeys, we sought

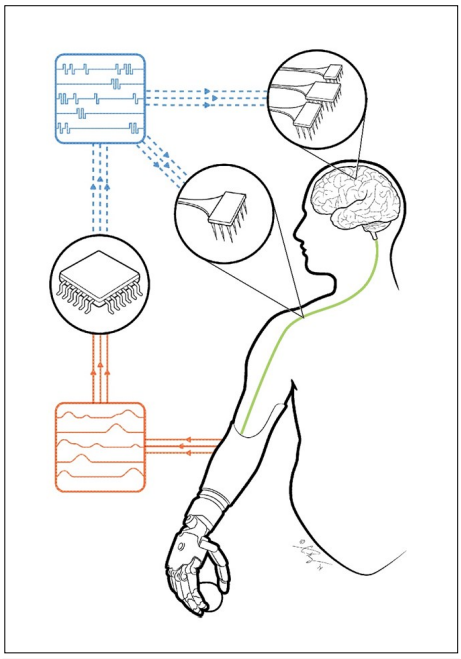


Figure 1: Schematic of a somatosensory neuroprosthesis. Signals from touch sensors on the prosthetic hand (orange arrows/traces) are converted into patterns of electrical stimulation (blue pulse trains/arrows) delivered to the nerve (for amputees) or to the brain (for tetraplegic patients). (Released)

to develop ways to stimulate S1 and convey information about contact location and pressure intuitively. To this end, we leveraged what we know about how contact location and timing are encoded in S1 of intact individuals and attempted to reproduce these natural patterns of neuronal activation through electrical stimulation.

In these experiments, we stimulated the brain with arrays of electrodes chronically implanted in S1. Our strategy consisted of training the animals to discriminate touches applied to their native hands. When the animals were trained on the task, we replaced some of the touches with small electrical pulse trains delivered to S1. We then assessed whether the animals responded to the electrical stimuli as they did to the touches they replaced. Importantly, the patterns of electrical stimulation were inspired by our knowledge about how location and pressure are represented in the brain.

Contact location has long been thought to be represented by a so-called place code. Touching different patches of skin activates different populations of neurons, and nearby neurons tend to respond to nearby patches of skin. Our ability to identify where we are touched is thus thought to be mediated by the location of the activated neurons within S1. We tested this by training animals to do a location discrimination task: We touched them sequentially at two locations of the skin and asked them whether the second touch was to the left or the right of the first. [8] Once the animals were trained, we replaced one of the touches with an electrical stimulus applied to an electrode that responded to the corresponding patch of skin. So, for example, we might touch the index fingertip, then the middle fingertip of the left hand, and the animal would correctly respond 'right.' Then, we might touch the middle fingertip of the left hand and electrically stimulate through an electrode located in a different region of S1 corresponding to the index fingertip. Lo and behold, the animal responded 'left,' as if we had actually touched its index finger. Across a wide variety of stimulation conditions, the animals responded as if they had been a touched in the location corresponding to that receptive field of the stimulating electrode. In other words, stimulating through individual electrodes evokes highly localized touch sensations. This phenomenon can then be exploited to convey information about contact location.

The magnitude of touch sensations tracks the pressure exerted on the skin: When we press weakly on the skin, we experience a weak sensation. When we press strongly on the skin, we experience a strong sensation. In S1, increasing pressure results in an increased response in active neurons and in the recruitment of nearby neurons. Increasing the amplitude of electrical stimulation has an analogous effect: As we increase the stimulation current, neurons near the electrodes become more active and neurons further away from the electrode become activated. We carried out a series of experiments to test whether information about pressure could be conveyed by varying the stimulation amplitude. These experiments culminated in a sensory encoding algorithm that converted skin pressure into stimulation current such that the magnitude of the electrically induced sensation matched that of the corresponding mechanical pressure sensation. We implemented this function to convert, in real time, the output of pressure sensors on prosthetic fingers into an appropriate electrical stimulus. We then demonstrated that animals could discriminate changes in pressure just as well when the touches were delivered to their native finger or to a prosthetic finger coupled with our algorithm.

To restore touch in a tetraplegic patient, then, the trick is to connect the electrodes implanted in S1 to the appropriate sensors on the hand. To this end, the prosthetist can stimulate through each electrode in turn and ask the patient where he or she experienced the sensation. Indeed, we have shown that stimulation through individual electrodes evokes highly localized tactile sensations. For example, if the patient reports that stimulation of electrode 23 evokes a sensation on the thumb tip, then electrode 23 should be connected to the sensor on the thumb tip. Anytime the thumb touches something, electrical stimulation will be delivered through electrode 23. To determine how much current to deliver through the electrode given a level of sensor output, we can use the psychometric equivalence function, which converts pressure into current. That way, the magnitude of the artificial tactile sensation experienced on the thumb will be appropriate to the amount of pressure that is exerted on the prosthetic thumb. Different electrodes will be connected to different sensors at

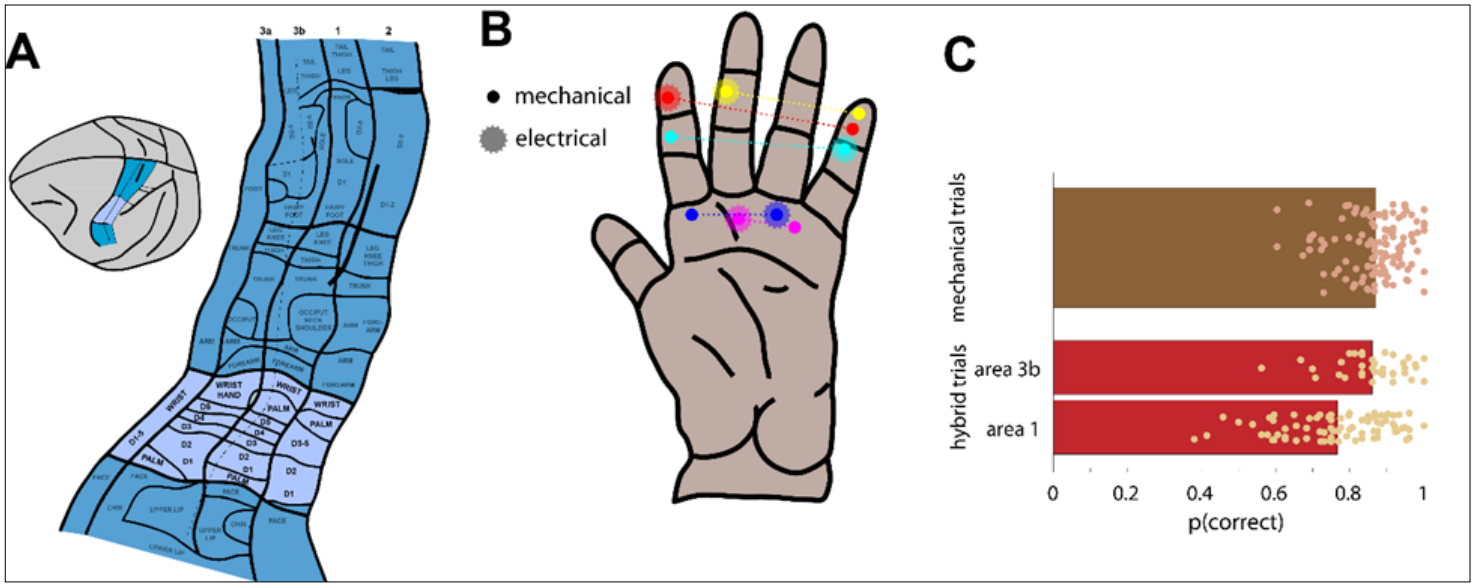


Figure 2: A. Organization of primary somatosensory cortex with the hand region highlighted. [adapted from Reference 19] B. Combination of skin locations at which pokes were delivered as well as receptive fields of electrodes through which stimulation was delivered. The lines link conditions that were paired in a trial. As can be seen, each electrode replaced a poke; that is, the receptive field of each stimulated electrode corresponded to one of the poke locations. C. Performance on mechanical and hybrid trials. Each dot represents a condition, bars represent the mean performance. [adapted from Reference 8] (Released)

different locations on the hand (using the approach sketched out above) to produce sensations that are experienced on the corresponding parts of the hand.

Conclusion

Contact force and location are two of the most basic aspects of touch so we initially focused on those. We are currently working on expanding the repertoire of artificially induced tactile sensations to include, for example, the sensation of motion across the skin or of texture. The key, we think, is to figure out how the brain represents this information and attempt to reproduce these natural patterns through electrical stimulation. When this technology comes to fruition, we anticipate that even the rudimentary tactile feedback described above will considerably improve the ability of patients to use robotic arms. Furthermore, it will lead patients to embody these robotic limbs, experience them as part of their own bodies.

As a result, wounded warriors outfitted with this advanced prosthesis may regain some of the independence that they lost as a consequence of their injuries.

Acknowledgments

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Multi-Phase Ceramic Composites as Hosts for NUCLEAR WASTE

By: Kyle Brinkman, Ph.D.

Introduction

With the global population approaching 8 billion by 2020, how societies handle their waste is an important measure of economic development with implications for national security. [1] According to the Institute for Energy Research, global energy consumption is expected to increase by 30 percent by 2020 with corresponding increases in by-products and waste generation. The generation of energy from fossil fuels, including recently discovered shale oil deposits, is fueled by the power sector. Electrical power generation from natural gas results in molybdenum rich waste streams that must be considered. Global coal utilization is also projected to increase resulting in a significant increase in coal ash, which possesses high levels of uranium (U), thorium (Th) and other heavy elements that require isolation and immobilization. [2] The civilian nuclear industry generates waste including spent nuclear fuel. In addition, legacy waste from national defense activities is currently being immobilized in glass vitrification facilities at the Savannah River Site in South Carolina and the Hanford Site in Washington State.

Storing and disposing of radioactive waste is a complex issue for the U.S. government and military from environmental and nonproliferation standpoints.

Currently, commercial spent fuel is stored on site in wet storage or dry cask storage facilities. The technology exists to reprocess the 96 percent of the remaining uranium in spent nuclear fuel for further use, however the resulting waste streams must be considered. [3] The ultimate composition of the streams depends on separation process used, but commonly have components of cesium and strontium streams, lanthanide streams, minor actinides and transition metals. Options to store this waste include encapsulation in glass or vitrification, crystalline ceramics, or some combination of the two approaches. [4] The resulting composite consisting of waste and host matrix is termed a waste form. Ceramics are a materials class defined by primarily ionic and covalent bonding with structural variations ranging from fully ordered crystalline (referred to as crystalline ceramics), to disordered amorphous (referred to as glass).

Glasses and ceramics have also been considered as candidates to make proliferation resistant materials for immobilization of excess grade weapons plutonium. In addition, re-processing of spent nuclear fuel represents a scenario for the diversion of actinide materials. Actinides could be recycled for re-use in nuclear processes. Nonproliferation, and thereby security of nuclear waste, is an important issue for the military.

Immobilization of actinide materials in ceramic waste forms is one strategy to reduce the threat of nuclear proliferation. Ultimately the waste form will be placed inside a metal canister, which will undergo storage in a geologic repository. The waste form can be considered a source term for transport of radionuclides into the environment; the goal of international waste form efforts is to design materials with low release rates over geologic time scales. The focus of this article will be to review technologies based on crystalline ceramics for the immobilization of waste streams resulting from potential commercial fuel reprocessing.

Current State of Art

Current research efforts are aimed at making the nuclear fuel cycle more effective by the development of next generation waste management technologies. One envisioned fuel-reprocessing technology would separate the fuel into several fractions, thus, partitioning the waste into groups with common chemistry. Ceramic (or crystalline) waste forms incorporate the radionuclides in the waste as part of the crystal structure. Tailoring of a ceramic waste form is based on the knowledge that there are many naturally produced minerals containing radioactive and non-radioactive species very similar to the radionuclides of concern in wastes from fuel reprocessing. For instance, there are minerals, or simply "rocks" which are natural analogues of the hollandite structure found in the Apuan Alps in Tuscany, Italy. A hollandite-type crystal structures appears to be a good candidates for the immobilization of common fission products such as cesium (Cs). [5] Similarly, in geologic rock formations, the material zirconolite has been found which is an attractive crystal structure for the immobilization of minor actinides. [6] Finally, perovskite and pyrochlore structures are attractive for the incorporation of lanthanide series elements and have known natural analogues found in geologic rock formations. [7]

Once the structures of interest are found by examining those commonly found in nature, the goal is to synthetically make these minerals in the laboratory. In principle, the crystalline systems should be similar to those found in nature which are more thermodynamicly stable compared to conventional amorphous or glass materials. A family of materials based on titanate ceramics have been thoroughly studied for use in immobilizing nuclear wastes (e.g., the synthetic rock, or Synroc, family) due to their natural resistance to leaching in water. Assemblages of several titanate phases have been successfully demonstrated to incorporate radioactive waste elements, and the multiphase nature of these materials allows them to accommodate variation in the waste composition.

Oxide	CS/LN/TM
Ag_2O	0.40
BaO	7.83
Br	0.08
CdO	0.39
Ce_2O_3	11.01
Cs_2O	10.22
Eu_2O_3	0.61
Gd_2O_3	0.57
In_2O_3	0.01
La_2O_3	5.62
MoO_3	13.88
Nd_2O_3	18.56
PdO	0.06
Pm_2O_3	0.06
Pr_2O_3	5.14
Rb_2O	1.50
Rh_2O_3	0.28
RuO_2	0.70
Sb_2O_3	0.04
SeO_2	0.29
Sm_2O_3	3.82
SnO_2	0.25
SrO	3.49
Tb_2O_3	0.01
TeO_2	2.33
Y_2O_3	2.23
ZrO_2	10.60

Table 1: Projected Waste Stream Compositions (wt%) for Waste Form Development.

Once the crystal structures have been achieved in the laboratory, the next step is to densify or compact the material to reduce the volume and eliminate porosity. While these materials are typically densified via hot isostatic pressing, recent work has shown that they can also be produced from a melt. For example, demonstrations have been completed using the Cold Crucible Induction Melter technology to produce several crystalline ceramic waste forms, including murataite-rich ceramics, zirconolite/pyrochlore ceramics, Synroc-C (zirconolite, hollandite, perovskite), aluminotitanate ceramics, and zirconia. [8,9] This production route is advantageous since melters are already in use for defense waste vitrification in several countries, and melter technology greatly reduces the potential for airborne contamination as compared to powder handling operations associated with hot isostatic pressing.

An example of one projected waste stream's composition for immobilization is given in Table 1. The cesium, strontium and lanthanide, CS/LN, composition is the result of a combination of the Cs/Sr separated stream and the Trivalent Actinide—Lanthanide Separation by Phosphorous reagent Extraction from Aqueous Komplexes, TALSPEAK, waste stream consisting of lanthanide fission products. The waste from these distinct separation steps are mixed together in the final stage resulting in a combined waste stream that requires immobilization.

Ceramic host systems for this study were selected based on the objectives of forming durable phases based on natural analogues described above, using a minimum of additives to form the desired phases (i.e., achieving high waste loadings). Many of the elements in the waste stream are known to react with select additives to form stable crystalline phases of the types perovskite, pyrochlore, hollandite and zirconolite. Elements with a +3 valance such as the most prevalent lanthanide in the waste stream, Nd^{+3}, readily form ABO_3 perovskite and related pyrochlore structures with titanium resulting in $NdTiO_3$ and $Nd_2Ti_2O_7$ type phases, respectively. [10,11] The Cs and Rb elements in the waste are known to partition to a hollandite structure with the formula of $(Ba_xCs_y)(M, Ti)_8O_{16}$ with $M=Al^{+3}$, Mn^{+3}, Fe^{+3}, Ga^{+3}, Cr^{+3}, Sc^{+3}, Mg^{+2} containing mixtures of divalent and trivalent cations. [12] A $CaZrTi_2O_7$ zirconolite crystalline phase has been demonstrated to incorporate the Zr transition metal waste element and minor actinide species resulting from inherent inefficiencies in the separation processes. [13]

Commonly available additives such as Al_2O_3, BaO, CaO, TiO_2, and Fe_2O_3 are used to tailor waste forms based on the waste streams listed Table 1. The choice of additives and targeted waste form compositions are calculated to form the desired phases:

- Zirconolite: example, $CaZrTi_2O_7$
- Perovskite/Pyrochlore: example, $NdTiO_3/Nd_2Ti_2O_7$
- Hollandite: example, $Ba_1Cs_{0.28}Al_{1.46}Fe_{0.82}Ti_{5.72}O_{16}$

Different multiphase compositions were prepared in this manner with ~25 weight percent waste loading and varying concentrations of CaO, Al_2O_3, BaO, Cr_2O_3, Fe_2O_3 and TiO_2 additives. The microstructures of select samples are presented in Figure 1 along with Table 2 indicating the elemental composition and crystalline phases observed.

There have been several comparative studies of crystalline ceramic waste forms produced by hot pressing and inductive melting. [14,15] These prior studies have indicated that the specimens in general exhibited similar mineral compositions. In addition, there was particular interest regarding differences in phase formation,

Table 2: Multiphase Waste Form Cr/Al/Fe Hollandite *with* Ti/TiO_2 Processing Comparison -Summary of Elements and Crystalline Phases *(*Crystalline phases determined from XRD measurements and EDAX elemental analysis)*

Spot	Elements (Major, Minor)	Crystalline Phases*
1	O,Al	Al_2O_3
2	O,Ti	TiO_2
3	O,Ti,Ca,Ba,Fe,Cr, (Nd,Zr,Cs,Al)	Hollandite
4	O,Ti,Y, (Fe)	$(A^{+3})_2Ti_2O_7$
5	O,Ti,Zr,Ca, (Fe,Nd)	$CaZrTi_2O_7$
6	O,Ti,Ce,Nd,Pr,La,Y, (Ba,Fe,Al,Cr)	$(A^{+3}{}_xB^{+2}{}_{1-x})TiO_3$, $(A^{+3}{}_xB^{+2}{}_{1-x})_2Ti_2O_7$

elemental partitioning and microstructural variation as a function of waste form composition and processing conditions. In recent studies, common microstructural differences observed between samples processed by a melt and crystallization route and solid-state sintering routes include an order of magnitude increase in grain size with melted ceramics along with an increase in porosity. [9,16]

Advanced Techniques for Characterization

While these materials have been successfully synthesized from a variety of fabrication methods, a greater understanding of the elemental partitioning, microstructural features, and connectivity of the phases and corrosion behavior as a function of processing variations is needed. Current work aims to systematically fabricate and characterize multi-phase waste form compositions with varied microstructures followed by advanced 3D characterization of their interconnected network, including residual porosity. Material system modeling will incorporate elemental release and the interconnected microstructural network of phases to better understand the material systems' performance and degradation. In order to address this need of advanced characterization, we are currently interrogating the 3D structure of multi-phase ceramic waste forms using Focused Ion Beam-Scanning Electron Microscopy techniques and full-field, x-ray computed tomography performed on synchrotron-based transmission x-ray microscopes. [17,18] The use of high-brilliance synchrotron sources permits the use of a tunable, monochromatic beam to perform imaging with elemental and chemical bonding sensitivity. The incident beam can be tuned to just below and above a characteristic absorption edge for one of a material's constituent elements, producing contrast in the resultant images as data are collected at either side of the absorption edge. Contrast appears wherever that constituent element is present in the sample, and the magnitude of the contrast is dependent on the prevalence of that element. Such a procedure can be repeated in succession for multiple elements within the sample, thus creating an imaging capability with elemental sensitivity.

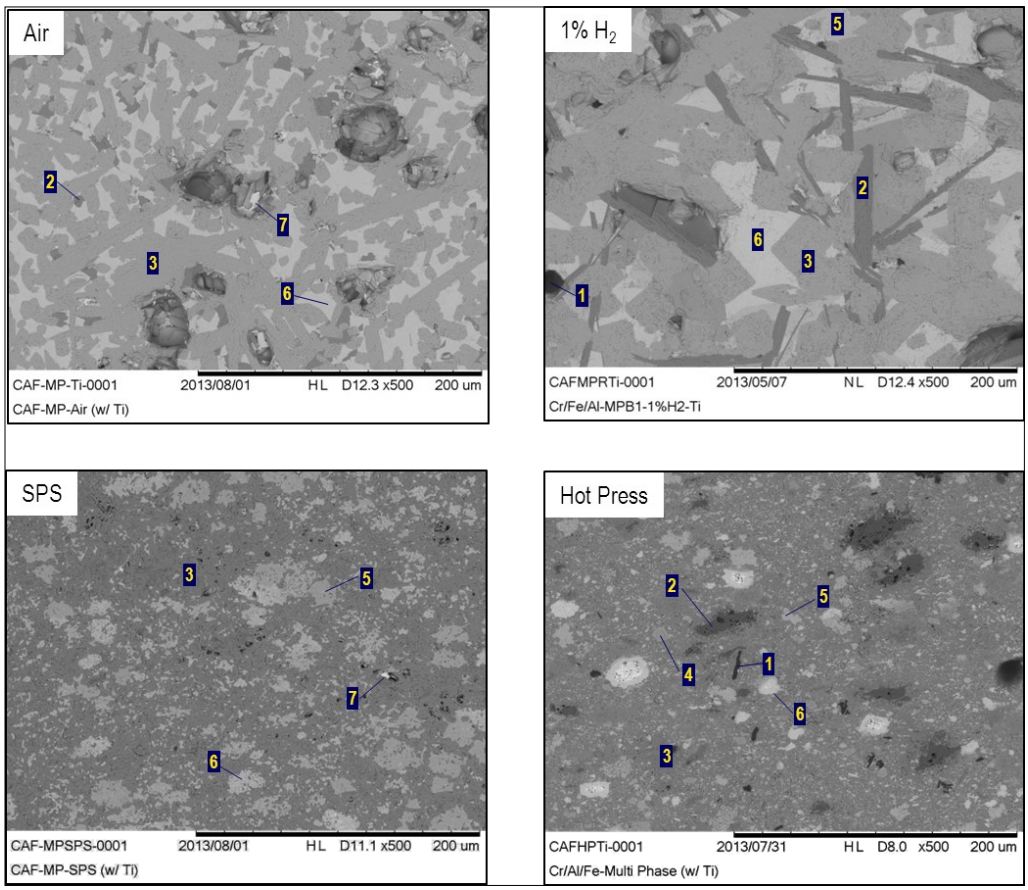

Figure 1: Multiphase Waste Form Cr/Al/Fe Hollandite with Ti/TiO_2 Processing Comparison-Backscattered Electron Micrograph (Released)

Conclusion

Proper storage and immobilization of nuclear waste is essential to protecting the United States, and its warfighters, from nuclear proliferation threats. Because global energy consumption is expected to continue to rise, nuclear waste storage will be a long-term concern for the United States.

Crystalline ceramics are a promising strategy for the immobilization of nuclear waste. These materials have been successfully fabricated with a range of

waste elements and under a wide variety of processing conditions. Differences in microstructure and elemental partitions have been observed with different processing methods. For instance, melt-processed samples displayed a high degree of substitution and variation of composition within grains was observed along with large (10-200 micron), irregularly shaped grains along with large voids. The impact of processing induced microstructural differences on the long term durability of these material systems requires additional attention. Currently, advanced 3D characterization of the interconnected network using electron microscopy and synchrotron X-ray techniques, including residual porosity is underway. Material system modeling that can incorporate elemental release and the interconnected microstructural network of phases to better understand the material systems' performance and degradation is also a need that is being addressed.

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